	US ATLAS **HL-LHC Upgrade** **BASIS of ESTIMATE (BoE)**	**Date of Est:** **3/31/2017** **Prepared by:** **Mark Oreglia** **Responsible Inst: University of Chicago** **Docdb #: HL-LHC-doc-28**

WBS number: 6.5.1	**WBS Title: Tile Calorimeter Main Board**

WBS Dictionary Definition:
This WBS covers the fabrication of the main boards (MB) which manage the data flow, power distribution, monitoring, and calibrations of the Tile Calorimeter (TileCal) front-end electronics. This includes the design, layout and construction of the printed circuit board (PCB), procurement of commercial components, and board assembly, burn-in and testing. It includes the costs of prototypes and the intermediate steps required to validate the board design. 1,024 boards are needed for the detector.

Estimate Type (check all that apply – see BOE Report for estimate type by activity):

___ Work Complete
___ Existing Purchase Order
___ Catalog Listing or Industrial Construction Database
_X_ Documented Vendor Estimate based on Drawings/ Sketches/ Specifications
_X_ Engineering Estimate based on Similar Items or Procedures
_X_ Engineering Estimate based on Analysis
_X_ Expert Opinion

Supporting Documents (including but not limited to): Attachments 1-6

Details of the Base Estimate (Explanation of the Work)

R&D Phase

The R&D phase during CY2017-19 consists of several design iterations based on feedback from bench- and beam-tests of prototype demonstrator units. ATLAS requires radiation certification of the components according to a strict rubric (single-batch component purchases lessen the certification burden); this requires design and construction of radiation certification boards followed by exposure to ionizing radiation and hadron beams, and finally assessment of performance.

MREFC Construction Phase

Production tasks include procurement, monitoring of outsourced assembly, elevated temperature burn-in of cards with testing and repair, shipping to CERN, and assembly onto the TileCal "drawer" mechanical structure for acceptance testing at CERN. Preproduction of 100 boards is needed prior to the Production Readiness Review (PRR). These will be used as spares since experience with the current TileCal detector has shown that approximately 10% of on-detector parts are needed as spares for replacement of non-functioning units during access periods.

Total Cost By Task Group

	Labor Hours	Labor Cost	Material Cost	Travel Cost	Total Cost	Contingen
:WS	**19,091**	**1,657,251**	**1,728,892**	**131,309**	**3,517,452**	**728,**
6.05.01.01 / UCH Chicago	**19,091**	**1,657,251**	**1,728,892**	**131,309**	**3,517,452**	**728,**
01 - Demonstrator - 2 Beam Tests	**317**	**31,462**	**90,000**	**6,476**	**127,939**	**1,**
Engineer	267	28,183			28,183	
Equipment			90,000		90,000	
Foregin Travel				6,476	6,476	1,
Technician	50	3,280			3,280	
					0	
02 - Radiation Certification	**1,750**	**175,761**	**30,000**	**7,108**	**212,870**	**59,**
Domestic Travel				632	632	
Engineer	1,523	160,938			160,938	46,
Equipment			30,000		30,000	5,
Foregin Travel				6,476	6,476	1,
Technician	227	14,823			14,823	5,
					0	
03 - MB Final Design	**1,621**	**167,225**	**30,000**	**6,671**	**203,896**	**70,**
Engineer	1,444	155,681			155,681	57,
Equipment			30,000		30,000	7,
Foregin Travel				6,671	6,671	1,
Technician	177	11,544			11,544	4,
					0	
04 - Pre-production	**5,030**	**505,234**	**356,924**	**24,847**	**887,004**	**281,**
Domestic Travel				335	335	
Engineer	3,875	437,192			437,192	181,
Equipment			356,924		356,924	69,
Foregin Travel				24,512	24,512	4,
Student	241	5,586			5,586	2,
Technician	915	62,456			62,456	23,
					0	
05 - Production Batch 1	**1,041**	**82,379**	**975,646**	**9,187**	**1,067,212**	**117,**
Domestic Travel				89	89	
Engineer	481	55,572			55,572	12,
Equipment			975,646		975,646	97,
Foregin Travel				9,099	9,099	1,
Student	281	6,883			6,883	1,
Technician	279	19,925			19,925	3,
					0	
06 - Production Batch 2	**640**	**44,243**	**18,067**	**180**	**62,489**	**10,**
Domestic Travel				180	180	
Engineer	241	28,481			28,481	5,
Equipment			18,067		18,067	1,
Student	281	7,089			7,089	1,
Technician	118	8,673			8,673	1,
					0	
07 - Production Batch 3	**640**	**44,419**	**18,305**	**182**	**62,907**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
08 - Production Batch 4	**640**	**44,419**	**18,305**	**182**	**62,907**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,

Technician	118	8,711			8,711	1,
					0	
09 - Production Batch 5	**640**	**44,419**	**18,407**	**182**	**63,008**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,407		18,407	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
10 - Production Batch 6	**640**	**44,419**	**18,305**		**62,725**	**10,**
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
11 - Production Batch 7	**640**	**44,419**	**18,305**	**182**	**62,907**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
12 - Production Batch 8	**640**	**44,419**	**18,305**	**182**	**62,907**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
13 - Production Batch 9	**640**	**44,419**	**18,305**	**182**	**62,907**	**10,**
Domestic Travel				182	182	
Engineer	241	28,619			28,619	5,
Equipment			18,305		18,305	1,
Student	281	7,089			7,089	1,
Technician	118	8,711			8,711	1,
					0	
14 - Production Batch 10	**640**	**44,943**	**18,363**	**182**	**63,488**	**10,**
Domestic Travel				182	182	
Engineer	241	28,906			28,906	5,
Equipment			18,363		18,363	1,
Student	281	7,195			7,195	1,
Technician	118	8,842			8,842	1,
					0	
15 - Production Batch 11	**640**	**45,752**	**18,854**	**188**	**64,794**	**11,**
Domestic Travel				188	188	
Engineer	241	29,478			29,478	5,
Equipment			18,854		18,854	1,
Student	281	7,302			7,302	1,
Technician	118	8,972			8,972	1,
					0	
16 - Production Batch 12	**640**	**45,752**	**18,854**	**188**	**64,794**	**11,**
Domestic Travel				188	188	
Engineer	241	29,478			29,478	5,
Equipment			18,854		18,854	1,

Student	281	7,302			7,302	1,
Technician	118	8,972			8,972	1,
					0	
17 - Production Batch 13	**640**	**45,752**	**18,896**	**188**	**64,836**	**11,**
Domestic Travel				188	188	
Engineer	241	29,478			29,478	5,
Equipment			18,896		18,896	1,
Student	281	7,302			7,302	1,
Technician	118	8,972			8,972	1,
					0	
18 - Production Batch 14	**640**	**45,752**	**18,854**	**188**	**64,794**	**11,**
Domestic Travel				188	188	
Engineer	241	29,478			29,478	5,
Equipment			18,854		18,854	1,
Student	281	7,302			7,302	1,
Technician	118	8,972			8,972	1,
					0	
19 - Production Batch 15	**213**	**15,430**	**6,195**	**188**	**21,813**	**3,**
Domestic Travel				188	188	
Engineer	60	7,370			7,370	1,
Equipment			6,195		6,195	
Student	70	1,825			1,825	
Technician	82	6,235			6,235	1,
					0	
20 - Acceptance at CERN	**602**	**74,137**		**19,422**	**93,559**	**33,**
Engineer	602	74,137			74,137	29,
Foregin Travel				19,422	19,422	3,
					0	
21 - Expert Week at CERN	**201**	**22,492**		**55,203**	**77,695**	**20,**
Engineer	201	22,492			22,492	8,
Foregin Travel				55,203	55,203	11,
					0	
and Total	19,091	1,657,251	1,728,892	131,309	3,517,452	728,

Cost Estimate Description

Design and Prototype Phase Costs

Prior to construction, there are three main activities. A final version of the boards for the demonstrator are being prototyped and tested, to be followed by a final design and prototype specific to the final HL-LHC design (e.g., the analog trigger circuits in the demonstrator design must be removed). Full radiation certification of the components requires building PCBs and DAQ to monitor devices during radiation exposures, and final assessment and documentation. Finally, a pre-production run of 100 boards is required for the Production Readiness Review. Our labor estimates for these tasks are based on our work on the demonstrator program since CY2012. Materials costs are based on the same experience and are dominated by the cost to produce 100 Main Boards (documented in the appendices). Travel is needed for expert weeks and system design workshops at CERN, and radiation tests at CERN and domestic locations.

Production M&S Costs

Cost of components and PCBs is taken from the Bill of Materials (BoM) for the production of prototype MB cards used in the "demonstrator" (a prototype Tile Calorimeter module currently undergoing testing at CERN) ; the BoM is shown in Attachment 1. This BoM shows CY2017 retail prices by Digikey. Our EE expert is confident (based on much experience with Arrow as a supplier) that for a full production lot the more expensive IC's, accounting for 87% of the cost, will realize a 20% or higher discount over the attached BoM. To get the best batch pricing and best meet radiation certification standards, all components will be purchased in one lot. We also have quotes from PCB manufacturers and an experienced PCB assembly firm for production quantities. Shipping costs are estimated based on a quote from UPS based on the size and weight of the required crating and insurance.

Production Labor Costs

The Main Board is a complex 16-layer PCB with a large number of ball-grid mounted integrated circuits. Experience acquired during production of prototype boards for a demonstrator module proved that the assembly process by outsourced firms needs to be monitored by an experienced Electrical Engineer (EE) who can aid in debugging faults in the process early on. It is also important for a trained Electronics Technician (ET) to perform an initial test on bare PCBs and again as they arrive from the assembly house to detect and repair faults. The assembled boards are received from the vendor at the University of Chicago, where they are mounted in burn-in fixtures and monitored in real time during temperature cycling over a 5 day period to identify weak and faulty components. This process requires that the front-end cards (FEB, manufactured by a non-US group) be connected to the MB during the burn-in. Experience from the production of the motherboards in the current detector, and especially 2016 production of MB prototypes, suggests that approximately 5-10% of the boards will need rework due to faulty components or soldering. Depending on the severity of the problem, the diagnosis and repair will be done by an EE or ET. Undergraduate students (UG) will be employed to mount boards in the burn-in fixtures, monitor them periodically, and dismount and store units that pass. The head EE will maintain an inventory database containing test results and unit history. Experience by the Chicago group from the production of 1100 motherboards for the current ATLAS detector showed that the burn-in and repair process required about 75% FTE labor by an EE and a Scientific Research Associate (which would be covered in this project by two EE's) and approximately 25% FTE oversight by the head EE. Shipping the boards in batches to CERN will incur materials and ET labor costs, and significant time by the EE is required at CERN to attend two expert weeks per year and train staff to do acceptance tests. Labor costs for the EE's and ET working in the Electronics Development Group (EDG) incur no overhead.

Labor FTEs are estimated based on experience with the recent prototypes produced for the demonstrator and our experience in producing the motherboards for the current ATLAS Tile calorimeter. The work is broken down as follows.

- Parts selection, negotiating select lots, inventory, test, stock: EE and ET.

Then there are 15 overlapping 9-week cycles of MB production. The first lot of 40 MB has a learning-curve factor, taking the same amount of time as the subsequent 13 batches of 80 MB. The last cycle produces the final 20 MB, but we allocate the same level of effort to cover final documentation, cleanup, and dismantling (or possibly production of more boards if yield permits).

For EACH CYCLE the tasks are

- Manage parts, short-test bare PCBs (ET)
- Oversee PCB assembly, initial testing, debugging with assembly house (EE,ET)
- Mount in burn-in fixtures; supervise students, test, document (EE,ET,UG)
- Diagnose, document, and repair failures (EE, ET)
- Inventory, document, crate and ship to CERN (ET)

At completion of production, the head EE will spend time at CERN for final QA, documentation, and integration.

- Acceptance test training at CERN and system integration meetings

The estimate of schedule and effort in the resource loaded schedule agrees within 10% with that expended in the production of the current TileCal motherboards. The latter is broken down in detail in the attachments.

Uncosted Labor

In addition to the costed labor, production will require 20% of the faculty PI and 50% of a postdoctoral scholar and some fraction of graduate student participation as uncosted labor. Additionally, some of the mounting and acceptance testing at CERN is expected to be done by uncosted labor by collaborators or Chicago postdocs and students stationed at CERN.

Travel Costs

Travel to CERN by the EE is needed during the design and production phases to attend expert weeks and to train staff to do the acceptance tests. We have estimated that two week-long trips per year will be necessary, based on our experience in constructing the demonstrator as well as the motherboard production during 2000-2003; the average cost of a week at CERN is estimated to be $2570, exclusive of indirect costs. A breakdown of this estimate is provided below. Also included for the PCB assembly process are commuter trips to Schaumburg, IL, so the EE can debug the process with the assembly house engineers; this is a local trip incurring only mileage reimbursement of $50 per trip; there is no overhead on this travel by EDG staff.

Assumptions:

- Chicago "3in1" version of FEB adopted. MB components (no ADCs!) would be 15-20% lower for other FEB versions (but the same effort is needed for production and burn-in).
- Negotiate 20% quantity discount on ICs (as has been the case on all our e-shop projects)
- Timely receipt of FEBs from Clermont-Ferrand
- Component failure rate < 10% (from experience with demonstrator)
- MB rework rate < 15% (from experience with demonstrator)
- Most of the acceptance testing at CERN is done by uncosted labor and collaborators

Schedule:

ATLAS management has scheduled installation of the Tile Calorimeter modules to begin early in CY2024. Consequently, the complete number of 256 tested and assembled drawers must be ready by CY2024Q2. To meet this target with available manpower and resources, 18 months of production are necessary over two years. These requirements call for the following timeline (calendar years):

- 2018-19: final design and prototype
- 2019/Q2: parts procurement and preproduction run
- 2020/Q2: procurement for production runs
- 2020/Q3 – 2022/Q3: production and testing of 1100 boards
- 2021-23: acceptance testing at CERN and mounting on drawer structures
- 2024/Q1: full system testing and start of installation

Risk Analysis: in risk registry

Comments:

An alternative front-end card might be selected by the collaboration. Both possible alternatives (ASIC-based QIE and FATALIC FEB's) would involve somewhat simpler main boards since the ADC is on the FEB ASIC. In the event of an alternative FEB downselect, the Chicago role would not be significantly altered. Main Board production, burn-in, testing, and repair would be very similar to that estimated in this proposal.

Note on Chicago Rates:
The labor by EE, ET is supplied by the University of Chicago Electronics Development Group, which is a recharge operation that simply charges an hourly rate; therefore, there are no associated fringe or indirect rates. Material, supplies, and equipment costing less than $5000 are subject to a 58% IDC and are free of IDC if in excess of $5000. Travel is subject to the 58% IDC. Undergraduate students are costed at an hourly rate subject to the 58% IDC; a fringe rate of 7.2% (subject to the IDC) is charged for the summer quarter only.

Note on Attached Quotes:
Shown are quotes from 2015 and again from February 2017. They amount to nearly identical total cost.

Attachments:

- Attachment 1: Bill of Materials
- Attachment 2: Vendor Quote: PCB assembly
- Attachment 3: UPS shipping quote, with insurance
- Attachment 4: Actual schedule of original Tile motherboard production
- Attachment 5: Production rework for 2001-3 motherboards on current detector

- Attachment 6: Cost of 1 week trip to CERN

Attachment 1: Bill of Materials

		B2842 Component Order List							
			Fukun Tang						
			ftang@uchicago.edu						
			773-834-4286						
			2/16/2017 update						
Item#	Company	Part name	Part #	Digikey #	Geometry	Qty/BD	Unit Price	Qty Order	subtotal $
2	Maxim	16-bit ADC	MAX1169BEUD+	MAX1169BEUD+-ND	TSSOP14	12	$18.25	14400	$218.94
3	Linear Tech	Oct 12-bit DAC	LTC2656IUFD-L12#PBF	LTC2656IUFD-L12#PBF-ND	QFN20_4x5mm	8	$12.210	9600	$97.68
4	Linear Tech	40Mbps 12-bit ADC	LTC2264CUJ-12#PBF	LTC2264CUJ-12#PBF-ND	QFN40_6x6mm	12	$18.070	14400	$216.84
5	Linear Tech	Op Amplifier	LTC2051CS8#PBF	LTC2051CS8#PBF-ND	soic8	2	$2.150	2400	$4.30
6	Linear Tech	Dual 4A DC/DC	LTM4619EV#PBF	LTM4619EV#PBF-ND	uModule_144	4	$20.340	4800	$81.36
7	Linear Tech	Negative DC/DC Controller	LT3759EMSE#PBF	LT3759EMSE#PBF-ND	MSOP12_TPAD	2	$2.850	2400	$5.70
9	Altera	Serial EPROM	EPCS4SI8N	544-1379-5-ND	soic8	4	$14.950	4800	$59.80
10	Altera	FPGA	EP4CE10F17C7N	544-2668-ND	FBGA256_17x17mm	4	$33.670	800	$134.68
13	Vishay	MOSFET	SI7848BDP-T1-GE3	SI7848BDP-T1-GE3CT-ND	soic8_ppak	2	$0.647	2400	$1.29
14	ECS	40MHz Clock Generator	ECS-3525-400-B-TR	XC1057CT-ND	5mmx3.2mm	4	$1.417	5000	$5.67
20	Molex	400-pin Aray Male Conn	45970-4715	WM4985CT-ND	400-pin Male Conn.	1	$18.343	1200	$18.34
1	Rohm Semi	Schottky 30V 5A Diode	RB085B-30TL	RB085B-30TLCT-ND	DPAK	4	$0.459	5000	$1.84
11	Littlefuse	3A FUSE BLOK	01543.15DRL	01543.15DRL-ND	smf_fuse_blok	2	$1.190	3000	$2.38
21	FCI	5-pin signal connector	berg_conn5		berg_conn5	12	$0.100	100	$1.20
22	Harwin Inc	10-pin JTAG Connector	M50-3500542	952-1383-ND	jtag_connst	2	$0.658	2400	$1.32
23	Circuit Asembly	40-pin ribbon connector	ca40nfhlr_ra		ca40nfhlr	12	$0.250	100	$3.00
26	Molex	4-pin power connector	0039301040	WM1352-ND	4-pin power conn	3	$0.364	3600	$1.09
27	Molex	3-pinpower connector	0039303035	WM18446-ND	3-pin power conn	2	$0.444	2500	$0.89
28	CTS	4-pos dip switch	218-4LPST	CT2184LPST	4-pos sm dip switch	2	$0.796	2400	$1.59
30	ERJ	RES 0.0 OHM 1/10W JUMP 0402 SMD	ERJ-2GE0R00X	P0.0JTR-ND	R0402	38	$0.002	45600	$0.06
31	KRL	RES 0.005 OHM 1W 1% 0805	KRL2012E-M-R005-F-T5	408-1595-1-ND	R0805	2	$0.153	2400	$0.31
32	ERJ	RES 22.0 OHM 1/10W 1% 0402 SMD	ERJ-2RKF22R0X	P22.0LTR-ND	R0402	20	$0.002	30000	$0.05
33	ERJ	RES 51.0 OHM 1/10W 1% 0402 SMD	ERJ-2RKF51R0X	P51.0LTR-ND	R0402	48	$0.002	60000	$0.11
34	Yageo	RES 56.0 OHM 1/16W 1% 0402 SMD	RC0402FR-0756RL	311-56.0LRTR-ND	R0402	12	$0.001	20000	$0.02
35	ERJ	RES 100 OHM 1/10W 1% 0402 SMD	ERJ-2RKF1000X	P100LTR-ND	R0402	36	$0.002	50000	$0.08
36	ERJ	RES 499 OHM 1/10W 1% 0402 SMD	ERJ-3EKF4990V	P499HTR-ND	R0402	24	$0.002	30000	$0.05
37	ERJ	RES 1.00K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1001X	P1.00KLTR-ND	R0402	126	$0.002	160000	$0.29
38	ERJ	RES 1.21K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1211X	P1.21KLTR-ND	R0402	4	$0.003	10000	$0.01
39	ERJ	RES 1.50K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1501X	P1.50KLDKR-ND	R0402	2	$0.007	2400	$0.01
40	ERJ	RES 2.00K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2001X	P2.00KLTR-ND	R0402	4	$0.003	10000	$0.01
42	ERJ	RES 3.83K OHM 1/10W 1% 0402 SMD	ERJ-2RKF3831X	P3.83KLTR-ND	R0402	6	$0.003	10000	$0.02
43	ERJ	RES 4.99K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4991X	P4.99KLTR-ND	R0402	4	$0.003	10000	$0.01
44	ERJ	RES 9.10K OHM 1/10W 1% 0402 SMD	ERJ-2RKF9101X	P9.10KLTR-ND	R0402	2	$0.003	10000	$0.01
45	ERJ	RES 10.0K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1002X	P10.0KLTR-ND	R0402	98	$0.002	120000	$0.23
46	ERJ	RES 11.5K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1152X	P11.5KLTR-ND	R0402	2	$0.003	10000	$0.01
47	ERJ	RES 15.8K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1582X	P15.8KLTR-ND	R0402	2	$0.003	10000	$0.01
48	ERJ	RES 27.4K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2742X	P27.4KLTR-ND	R0402	2	$0.003	10000	$0.01
49	ERJ	RES 28.0K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2802X	P28.0KLTR-ND	R0402	4	$0.003	10000	$0.01
50	ERJ	RES 45.3K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4532X	P45.3KLTR-ND	R0402	2	$0.003	10000	$0.01
51	ERJ	RES 48.7K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4872X	P48.7KLTR-ND	R0402	2	$0.003	10000	$0.01
52	ERJ	RES 60.4K OHM 1/10W 1% 0402 SMD	ERJ-2RKF6042X	P60.4KLTR-ND	R0402	2	$0.003	10000	$0.01
53	ERJ	RES 84.5K OHM 1/10W 1% 0402 SMD	ERJ-2RKF8452X	P84.5KLTR-ND	R0402	2	$0.003	10000	$0.01
54	ERJ	RES 100K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1003X	P100KLTR-ND	R0402	2	$0.003	10000	$0.01
55	ERJ	RES 105K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1053X	P105KLTR-ND	R0402	2	$0.003	10000	$0.01
56	ERJ	RES 121K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1213X	P121KLTR-ND	R0402	2	$0.003	10000	$0.01
57	ERJ	RES 25.5 OHM 1/10W 1% 0402 SMD	ERJ2RKF25R5X	P25.5LTR-ND	R0402	24	$0.002	30000	$0.05
59	MURATA	CAP CER 12pF 50V 1% NP0 0402	GRM1555C1H120FA01D	490-6196-2-ND	C0402	12	$0.007	20000	$0.09
60	Kemet	CAP CER 22PF 10V 5% NP0 0402	C0402C220J8GACTU	C0402C220J8GACTU-ND	c0402	8	$0.062	10000	$0.49
61	TDK	CAP CER 1000PF 50V 5% NP0 0402	C1005C0G1H102J050BA	445-6846-2-ND	c0402	56	$0.017	70000	$0.93
62	TDK	CAP CER 10000PF 25V 10% X5R 0402	C1005X5R1E103K050BA	445-7386-6-ND	c0402	26	$0.007	40000	$0.17
63	TDK	CAP CER 0.1UF 16V 10% X5R 0402	C1005X5R1C104K050BA	445-4970-2-ND	c0402	649	$0.005	780000	$3.06
64	AVX	CAP CER 1UF 6.3V 10% NP0 0402	C2012C0G1H103J060AA	04026W105KAT2A-ND	c0402	60	$0.126	80000	$7.56
65	TDK	CAP CER 2.2UF 10V 10% X5R 0402	C1005X5R1A225K050BC	445-7392-2-ND	c0402	46	$0.057	60000	$2.60
66	TDK	CAP CER 4.7UF 10V 20% X5R 0402	C1005X5R1A475M050BC	445-8023-2-ND	c0402	26	$0.062	40000	$1.62
67	TDK	CAP CER 4.7UF 25V 10% X5R 0805	C2012X5R1E475K125AB	445-4116-2-ND	C0805	6	$0.056	8000	$0.34
69	Taiyo Yuden	CAP CER 100UF 16V 20% X5R 1210	EMK325ABJ107MM-T	587-3152-2-ND	C1210	28	$0.604	34000	$16.93
70	TDK	FERRITE CHIP BEAD 600 OHM SMD	MPZ2012S601A	MPZ2012S601A	F0603	32	$0.024	40000	$0.75
71	Copper Bussmann	INDUCTOR SHIELD DUAL 3.3UH SMD	DRQ127-3R3-R	513-1308-1-ND	DRQ127-3R3-R	2	$0.930	2450	$1.86
72	Samsung	10uF 6.3V 20% X5R 0402	CL05A106MQ5NUNC	1276-1451-1-ND	C0402	20	$0.115	30000	$2.30
73	Kemet	47uF 6.3V 20% X5R 0805	C0805C476M9PACTU	399-5506-1-ND	C0805	56	$0.187	67500	$10.46
74	Murata	47uF 10V 20% X5R 1206	GRM31CR61A476ME15L	490-5528-2-ND	C1206	72	$0.122	88000	$8.81
75	Molex	Crimp terminal	0457503112	WM10851-ND			$0.159	100	$0.00
76	Molex	4-pin power connmating socket	0039012040	WM3701-ND	Mating PN WM1352-ND		$0.208	100	$0.00
							Passive components		$72.65
							ICs		$844.61
							20% discount on ICs		-$168.92
77							PCB Q550		$240.00
78							Assy Q550		$182.00
							total MB cost		$1,170.34

Attachment 2: Vendor Quotes: PC boards and PCB assembly

Imagineering, Inc.

2425 Touhy Ave, Elk Grove Village,IL 60007
Tel (847) 806-0003 Fax (847) 806-0004

To: University of Chicago
PHYSICAL SCIENCES DIVISION, 5747 SOUTH ELLIS AVE-RM 303G
Chicago, IL 60637
Attn: Fukun Tang

Quote# 841247
Date 02/20/2017
CustID# UNI065

We are pleased to quote you the following as per your specifications and requirements. This quote is valid for 30 days. Please refer to the above quote number when placing an order. Feel free to call us if you have any questions.

Part Number - MAIN BOARD V3	Board Size - 27.165 x 3.937
Ref# - B2860	Panel Size - 0.000 x 0.000
Layers - 16	Array(Brds/Pnl) - n/a
Material - FR4 -170Tg	Routing - Individual
Thickness - 100'	Other Info -
Finish Type - Immersion Gold	Testing - YES

Hole Count - 3906	Mask Type - LPI	Silk Color(Top) - White
Tool Count - 11	Mask Color(Top) - Green	Silk Color(Bottom) - White
Smallest Hole Size - 010	Mask Color(Bottom) - Green	Min. Copper Wt. - 2.0
Min. Line Width - 005	Min. Spacing - 005	Slots/Cutout - 0
SMT Sides - Both Sides	SMT Pitch - 0.015	SMT Pads - 0

Special: Impedence Control

QUOTE INFORMATION BASED ON ABOVE SPECS.

Quantity	Turnaround (Working Days)	Unit Price	Line Total
10	15 Days	$740.00	$7400.00
20	16 Days	$515.00	$10300.00
1100	60 Days	$125.00	$137500.00

San Francisco Circuits

Bridging Concepts with Reality

Your Single Source Solution to All Your PCB Needs!
Thank you for your Request for Quotation

Quote# 41719

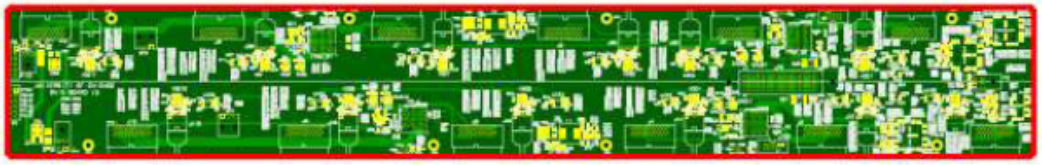
Item Description		
Part Number: B-2860	Revision: 2	Quote Date: 2/16/2017

Company Name: University of Chicago
Customer Name: Fukun Tang

Tel: 773.834.4286
Email: fukun.tang@gmail.com

FABRICATION Quotation - Unit Price

#	Type	Quantity (boards)	TurnTime	Unit Price	Tooling NRE	Electrical Testing	Total
1	Prototype	10	11 days	$587.60	$0.00	No Charge	$5,876.00
2	Prototype	10	16 days	$457.30	$0.00	No Charge	$5,473.00
3	Prototype	20	11 days	$549.90	$0.00	No Charge	$10,998.00
4	Prototype	20	16 days	$509.60	$0.00	No Charge	$10,192.00
5	Production	1,090	21 days	$265.20	$0.00	No Charge	$289,068.00



Board Specifications

- **Layers: 16**
- **Dimensions: 3.937 X 27.165**
- Specification: IPC 6012 Class 2
- Material: 370HR / IS410 or equivalent
- Thickness: 0.100”
- Trace/Space: 5 mil line/space
- Copper Weight: 1 oz/ 1 oz, 2 oz
- Controlled Impedance: +/-10% tolerance
- Minimum Hole Size: 10 mil
- Hole Count: 3906
- Drill to Copper: 10 mil or above
- SMD Pitch: 0.5 mm
- Solder Mask: LPI Green
- Silk Screen: White
- Final Finish: ENIG (Immersion Gold)
- Routing: Individual Routing

Comments:

San Francisco Circuits' Terms and Conditions: Quotation is valid for 30 days. Turn time begins upon receipt of Purchase Order and complete Gerber files. Files and Purchase Order must be received by 5PM for the following day to count as day one. For turn times 3 days or sooner, files and purchase order must be received by 3 PM. Credit terms subject to approval. San Francisco Circuits reserves the option to subcontract to an approved facility. No changes to these or any different terms on your purchase order shall be binding unless agreed upon in writing by San Francisco Circuits' management. In the event of non-conforming product, notification must occur within (30) calendar days of receipt. San Francisco Circuits' max liability for PCB fabrication is limited to bare PCB replacement only (bare board replacement only). Warranty does not apply after components are added to the PCB. San Francisco Circuits' max liability for PCB assembly is limited to the parts and services supplied. San Francisco Circuits' liability shall not exceed the price you paid us for the PCBs. Returns will not be accepted after (30) calendar days of receipt. Tooling and Test charges are non-exempt from sales tax. All credit card orders greater than $3,000 will be applied a 3% service fee.

San Francisco Circuits, Inc. 1660 S Amphlett Blvd #200, San Mateo, CA 94402
Tel: +1.650.655.7202 - Fax: +1.650.655.7206 - sales@SFcircuits.com

BESTProto Inc.
Your product development partner

QUOTATION

Date	Quote Number:
2/27/2017	6162

BESTProto Inc.
3603 Edison Place
Rolling Meadows IL 60008
Ph: 224-387-3280 Fax: 224-387-3290
www.bestproto.net

University of Chicago
Physical Sciences Division
5747 S. Ellis Ave GHJ 303
Chicago, IL 60637

BESTProto, Inc. is pleased to quote the following price and delivery information:

Item	Qty	Customer P/N, Description	Piece Price	*Lead Time
1	10	PCB Assembly (Labor Portion), B2800	321.80	10 Days
2	10	PCB Assembly (Labor Portion), B2800	418.30	5 Days
3	100	PCB Assembly (Labor Portion), B2800	213.10	TBD
4	1,100	PCB Assembly (Labor Portion), B2800	188.40	TBD
		*Lead times are subject to available capacity at the time of order. Standard lead time is approximately 10 days after receipt of all required parts and files.		
		Sales Tax if Applicable (10.0%)		

BESTProto Inc.
Your product development partner

QUOTATION

Date	Quote Number:
11/5/2015	5211

BESTProto Inc.
3603 Edison Place
Rolling Meadows IL 60008
Ph: 224-387-3280 Fax: 224-387-3290
www.bestproto.net

University of Chicago
Physical Sciences Division
5747 S. Ellis Ave GHJ 303
Chicago, IL 60637

BESTProto, Inc. is pleased to quote the following price and delivery information:

Item	Qty	Customer P/N, Description	Piece Price	*Lead Time
1	100	PCB Assembly (Labor Portion), B2800	190.20	10 Days
2	100	PCB Assembly (Labor Portion), B2800	247.20	5 Days
3	550	PCB Assembly (Labor Portion), B2800	182.00	10 Days
4	1,100	PCB Assembly (Labor Portion), B2800	180.00	20 Days
		*Lead times are subject to available capacity at the time of order. Standard lead time is approximately 10 days after receipt of all required parts and files.		
		Sales Tax if Applicable (9.0%)		

Attachment 3: UPS shipping quote, with insurance

Freight Service	Total	Ship Date	Expected Delivery to Destination*
UPS Air Freight Direct℠ (Non-Guaranteed)	1,166.98 USD	Thursday 03/09/2017	05:00 PM Tuesday 03/14/2017

Base Transportation:	215.97 USD
Delivery:	Included
Declared/Insured Value Surcharge:	736.10 USD
Customs Brokerage Related:	Included
Peak Season Surcharge:	0.00 USD
Electronic Export Information (EEI):	15.00 USD
Security Fee:	20.00 USD
Fuel Surcharge:	73.80 USD
Misc. Origin Fees:	80.00 USD
Misc. Destination Fees:	26.11 USD
Liftgate Required:	0.00 USD
Total:	**1,166.98 USD**

Freight Service	Total	Ship Date	Expected Delivery to Destination*
UPS Air Freight Consolidated℠ (Non-Guaranteed)	1,166.98 USD	Thursday 03/09/2017	05:00 PM Wednesday 03/15/2017

Base Transportation:	215.97 USD
Delivery:	Included
Declared/Insured Value Surcharge:	736.10 USD
Customs Brokerage Related:	Included
Peak Season Surcharge:	0.00 USD
Electronic Export Information (EEI):	15.00 USD
Security Fee:	20.00 USD
Fuel Surcharge:	73.80 USD
Misc. Origin Fees:	80.00 USD
Misc. Destination Fees:	26.11 USD
Liftgate Required:	0.00 USD
Total:	**1,166.98 USD**

Attachment 4: Actual schedule of original Tile motherboard production

Shpmnt Number	Boxes	Quantity					Date Shipped	Carrier	Tracking Number	Date Received	Comments
		MB 1	MB 2	MB 3	MB 4	Mezz.					
1	1	1	1	1	1	1	6-Jun-01	FedEx			For Clermont drawer integration on 18-Jun-01
2	4	4	4	4	4	4	15-Jun-01	FedEx	790937937090		
3	1	1	1	1	1	1	25-Jun-01	FedEx			Last set needed for July test beam
4	1	6	6	6	6	6	5-Jul-01	FedEx		11-Jul-01	
5	1	3	3	3	3	3	18-Jul-01	FedEx			
6	3	17	17	17	17	17	30-Oct-01	FedEx		1-Nov-01	
7	4	29	29	29	29	29	30-Nov-01	FedEx		5-Dec-01	
8	1	8	8	8	8	8	30-Jan-02	FedEx		5-Feb-02	
9	12	48	48	48	48	48	26-Feb-02	FedEx		8-Mar-02	
10	4	16	16	16	16	16	29-Mar-02	FedEx			
11	5	20	20	20	20	20	10-Apr-02	FedEx			
12	8	32	32	32	32	32	26-Apr-02	FedEx			
13	8	42	42	42	42	42	31-May-02	FedEx		3-Jun-02	
14	3	12	12	12	12	12	27-Jun-02	FedEx		2-Jul-02	
15	3	12	12	12	12	12	29-Jul-02	FedEx	790572380175	1-Aug-02	New ADC firmware in all 12 sets
16	1	4	4	4	4	4	31-Jul-02	FedEx		2-Aug-02	Old firmware in all 4 sets
17	2	8	8	8	8	8	26-Aug-02	FedEx		3-Sep-02	7 to CERN and 1 to Stockholm
18	1	4	4	4	4	4	30-Sep-02	FedEx		7-Oct-02	
19	1					4	31-Jan-03	FedEx		18-Feb-03	4 short MB4 sections [1]
20	2	9	9	9	9	9	8-May-03	FedEx		14-May-03	7 of these have no integrator ADC board
TOTALS		276	276	276	276	280					

Monthly Totals:						Integral Count	Integral Percent
June	6	6	6	6	6	6	2%
July	9	9	9	9	9	15	6%
August	0	0	0	0	0	15	6%
September	0	0	0	0	0	15	6%
October	17	17	17	17	17	32	12%
November	29	29	29	29	29	61	23%
December	0	0	0	0	0	61	23%
January	8	8	8	8	8	69	25%
February	48	48	48	48	48	117	43%
March	16	16	16	16	16	133	49%
April	52	52	52	52	52	185	68%
May	42	42	42	42	42	227	84%
June	12	12	12	12	12	239	88%
July	16	16	16	16	16	255	94%
August	8	8	8	8	8	263	97%
September	4	4	4	4	4	267	99%
October	0	0	0	0	0	267	99%
May '03	9	9	9	9	9	276	102%
Grand Totals:	276	276	276	276	276		
Fraction of Total	102%	102%	102%	102%	102%		

Attachment 5: Production rework for 2001-3 motherboards on current detector

Progress on rework of TTC Mezzanine Cards

23-Jul-03

	Number	Date	
Card sent to Promex for quote on rework	1		
Sample returned from Promex	1	9-Dec-02	
Richard sends first batch from CERN	103	9-Dec-02	
Cards sent to Promex from Chicago	103	16-Dec-02	
First article of production received from Proxmex	1	8-Jan-03	
Balance of cards received from Promex	102	15-Jan-03	
First shipment of reworked cards to CERN	50	17-Jan-03	
Second shipment of reworked cards to CERN	40	27-Jan-03	
5 MB1 sections shipped with reworked Mezz. Cds.	5	31-Jan-03	
Richard sends second batch from CERN	136[1]	5-Feb-03	
2nd batch of cards sent to Promex from Chicago	163	14-Feb-03	
2nd batch of cards sent from Chicago to CERN	155	15-Mar-03	28-Mar-03
9 MB sets sent, including reworked Mezz. Cards	9	8-May-03	
7 reworked Mezz. Cds. Shipped to CERN from Chica	7	11-Jul-03	

Totals

	Reworked	Need Rework	Total
At CERN/Stockholm/Clermont	266	10	276
In modules in Bldg. 175		5	
In Bldg. 40 (available for shipment)		5[2]	
Shipped to CERN 17 and 27-Jan-03	90		
Shipped with MBs on 3-Feb-03	5		
Shipped to CERN 15-Mar-03	155		
Shipped to CERN with MBs on 8-May-03	9		
Shipped to CERN on 11-Jul-03	7		
At Chicago	1[3]		1
At Promex	0	0	0
TOTAL	267	10	277

Mezzanine cards built (272+8)	280
Received from Promex after rework	
Batch 1	104
Batch 2	163
Batch 3	

Attachment 6: Cost of 1-week trip to CERN

Air fare: estimate for round trip Chicago-CERN: **$1800**
This is a list prepared by our Local Business Office representative of faculty air fares to CERN over the last year.

Depart	Return	Amount
12/7/2015	12/19/2015	$1,650.10
2/15/2016	2/19/2016	$2,428.16
2/19/2016	3/4/2016	$1,409.56
4/1/2016	4/16/2016	$1,707.56
5/20/2016	5/26/2016	$1,610.26
5/20/2016	6/3/2016	$1,434.36
7/15/2016	7/29/2016	$2,560.76
8/13/2016	9/2/2016	$1,710.26
10/7/2016	10/21/2016	$1,492.16
11/28/2016	12/9/2016	$1,784.36
TOTAL		$17,787.54
AVERAGE	10	$1,778.75

Air fare: $1800

Lodging: 7 days in CERN Foyer: **$560**

MIE: meals and incidentals: **$210**
Allowance of $30/day

Total for one week trip (unburdened): **$2570**